Analysis of friction models applied to the ground reaction forces during human gait

J. Ojeda[*], D. Infantes[#], J. Mayo[*]

[*] School of Engineering
University of Seville
Camino de los Descubrimientos s/n,
41092 Seville, Spain
joaquinojeda@us.es

[#] Faculty of Physic and
Mathematic Sciences
National University of Trujillo
Av. Juan Pablo II s/n, Trujillo,
Peru
daih_8913@hotmail.com

Abstract

Accurate definition of the foot-ground contact is crucial when direct simulations of human gait are performed using multibody techniques. This problem has been extensively analyzed in the literature [1,2]. Quite good approximations have been achieved in the case of the normal ground reaction forces. However, tangential or friction forces definition presents a higher level of complexity. Different approaches have been presented in the literature [3-5]. The most usual approach is the use of models based on the Coulomb law [4,5]. However, no good results are usually achieved. The goal of this work was to study the influence of the different terms and parameters of the friction force - relative velocity relation. Normal gait was measured in an adult male using 6 infrared Vicon cameras and a set of reflective markers. Ground reaction forces were collected with two AMTI force plates. An inverse dynamics problem has been solved. Ground reaction forces were defined as a function of the contact laws and the kinematics calculated from the markers data. Data obtained from the forces plates were used to validate the ground reaction forces estimated with the models. The plantar surface has been modelled as 5 contact points along the surface as shown in Figure 1. Viscoelastic elements were defined on each point to model the normal force [3] as shown in Equation (1).

$$F_N = \begin{cases} MAX(0, -kd_N - cv_N) & d_N < 0 \\ 0 & d_N \geq 0 \end{cases} \tag{1}$$

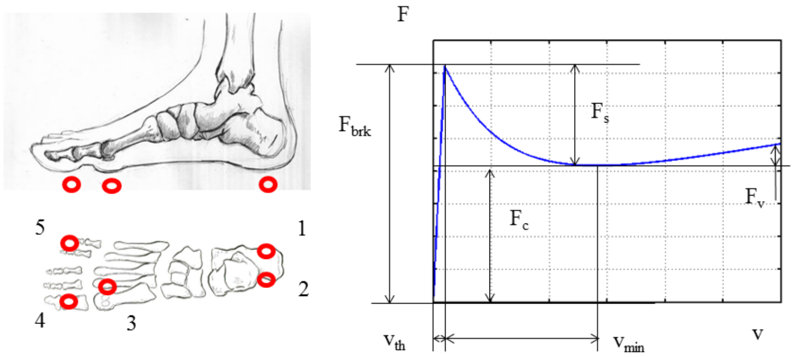

Figure 1: Left, position of the 5 points defined to estimate the ground reaction force. Right, general friction force – relative velocity relation. F_{brk}: Break-away force; F_C: Coulomb force; F_S: Stribeck force; F_V: viscous force; v_{th}: threshold velocity, defined to avoid numerical problems; v_{min}: range of velocity where the Stribeck force is defined.

Where d_N denotes the normal coordinate of the contact point, v_z its temporal derivative and c is the damping coefficient defined as a nonlinear function of the ground pseudo-penetration [3]. Tangential forces were implemented using a modification of the Coulomb law (see Figure 1 and Equation (2)).

$$F(v) = F_C + (F_S - F_C)e^{-\left|v/v_{str}\right|^{\sigma}} + F_v \quad (2)$$

Table 1: Numerical values of the parameters of the friction law. Units in I.S.

k	μ	F_{brk}	V_{str}	v_{th}	c_v	σ
1.5e4	0.25	1.2 F_C	0.85	1e-6	0.1	1

In Table 1 are shown the numerical values of the parameters. k is the stiffness of the elastic element in Equation (1). Coulomb force, F_C, was defined as μF_N, where F_N is the normal contact force and μ is the friction coefficient. In the interval from 0 to v_{th} a linear relation was assumed. Viscous friction, F_v, was defined as $c_v v$. Figure 2 shows the temporal evolution of the friction force and its components on each contact point. The estimated forces have been compared with experimental data. Results suggest that modelling Stribeck force improves the estimation of the friction forces on normal gait. The reason is the low values of the relative velocities in the slide contact between the foot and the ground. A parameter analysis is required to adjust the friction law and to improve the results.

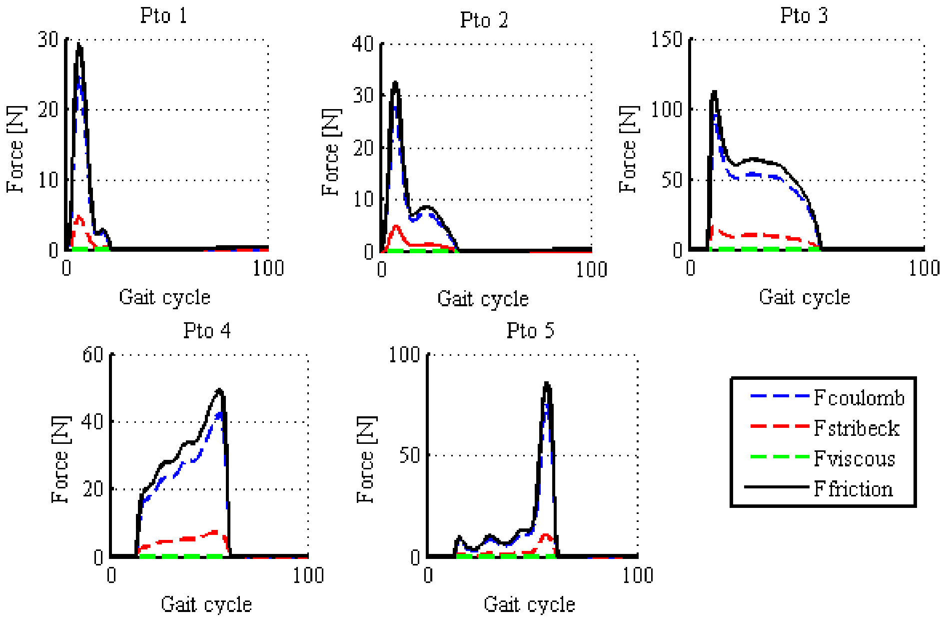

Figure 2: Temporal evolution along the gait cycle of the friction force and its different terms on the 5 points expressed in %.

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